

Physical Condition Measurement

Provides guidance on measuring the physical condition of ocean and coastal ecosystems for use in SEEA EA ecosystem condition accounts.

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OUTCOME

This Circular provides guidance on measuring the physical condition of ocean and coastal ecosystems for use in SEEA EA ecosystem condition accounts. On completing this Circular, users will be able to select appropriate physical state variables, establish reference conditions, rescale variables to dimensionless condition indicators on a 0–1 scale, and integrate physical condition data into the asset account structure defined in [TG-3.1 Asset Accounts](#). Physical condition measurement addresses the abiotic subset of ecosystem condition (temperature, salinity, dissolved oxygen, pH, turbidity, nutrients, and light attenuation), corresponding to ECT Classes A1 and A2 as defined in SEEA EA Table 5.1. This Circular does not cover biological condition variables (covered by TG-4.9) or the compilation of condition account tables (covered by TG-3.1).

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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DRAFT

***Framework position:** TG-4.8 sits in the data methods layer. It provides the measurement protocols and variable selection guidance for physical state variables that feed upstream into the ecosystem condition indicators described in TG-2.1 and TG-2.8, and from there into asset accounts compiled under TG-3.1. Users compiling condition accounts should read this Circular alongside [TG-4.9 Biological Condition Measurement](#), which covers the biotic counterpart to the abiotic variables described here.*

¶1 ⓘ **Framework Position**

¶2 TG-4.8 sits within Section 4 (Data Methods). It owns the abiotic condition variable – ECT Classes A1 and A2 – from selection through measurement protocol, data source and tier, reference condition, and rescaling to a dimensionless 0–1 score against that documented reference, with its uncertainty. It does not own what is built from those scores. Combining variables into an ECT-class or overall condition index is **TG-2.1 Aggregate Biophysical Indicators of Environmental State**; the SEEA EA Table 5.2 condition account is **TG-3.1 Asset Accounts** Section 3.5.2. Biotic variables are **TG-4.9 Biological Condition Measurement**.

1. Outcome

¶1 This Circular provides guidance on measuring the physical condition of ocean and coastal ecosystems for use in SEEA EA ecosystem condition accounts. On completing this Circular, users will be able to select appropriate physical state variables, establish reference conditions, rescale variables to dimensionless condition indicators on a 0–1 scale, and integrate physical condition data into the asset account structure defined in [TG-3.1 Asset Accounts](#).

¶2 Physical condition measurement addresses the abiotic subset of ecosystem condition (temperature, salinity, dissolved oxygen, pH, turbidity, nutrients, and light attenuation), corresponding to ECT Classes A1 and A2 as defined in SEEA EA Table 5.1¹. This Circular does not cover biological condition variables (covered by [TG-4.9](#)) or the compilation of condition account tables (covered by [TG-3.1](#)).

2. Requirements

¶1 Users should be familiar with the following circulars before working through this guidance:

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** – for the overall structure and purpose of ocean accounts
- ¶3 **TG-0.6 Glossary of Key Terms** – for canonical definitions of “condition variable”, “condition indicator”, and “reference condition”
- ¶4 **TG-0.7 Quality Assurance Principles** – for data quality, metadata, and uncertainty documentation requirements
- ¶5 **TG-4.1 Remote Sensing and Geospatial Data** – for satellite sensor selection, pre-processing, and spatial data handling
- ¶6 **TG-4.5 Integrating Research Data into Official Statistics** – for admitting in-situ oceanographic survey and monitoring data, including quality thresholds, spatial interpolation, and cross-validation
- ¶7 **TG-4.4 Citizen Science and Community-Based Monitoring** – for citizen science and community-based monitoring data in data-poor contexts

3. Guidance Material

3.1 Conceptual Framework

¶1 Physical condition measurement is anchored in SEEA EA Chapter 5, which establishes the Ecosystem Condition Typology (ECT), the concept of reference condition, and the rescaling of state variables to dimensionless condition indicators on a 0–1 scale. Physical condition captures the abiotic state of the ocean environment. The SEEA EA Ecosystem Condition Typology (Table 5.1) groups condition characteristics into three groups and six classes – Group A (abiotic) with classes A1 and A2, Group B (biotic) with classes B1 to B3, and Group C (landscape) with class C1. Abiotic condition is the two classes of Group A:

- ¶2 **ECT Class A1 – Physical state characteristics:** the thermal, hydrodynamic and optical properties of the water column (temperature, salinity, water clarity, stratification).
- ¶3 **ECT Class A2 – Chemical state characteristics:** the chemical composition of the water column (pH and aragonite saturation, dissolved oxygen, dissolved inorganic nutrients).

¶4 Class labels follow SEEA EA Table 5.1 exactly. [TG-3.1 Asset Accounts](#) Section 3.5.2 uses the same six classes, and a variable must carry the same class label in both circulars.

¶5 Physical condition is distinct from biological condition ([TG-4.9 Biological Condition Measurement](#)): physical variables measure the abiotic habitat envelope within which organisms live, whilst biological variables capture the biotic response of living organisms to that environment. Both are components of ecosystem condition as defined by SEEA EA Chapter 5 and both feed into asset accounts ([TG-3.1 Asset Accounts](#)).

¶6 **Reference condition** is the baseline against which current state is compared. SEEA EA paras 5.65–5.75 and Appendix A5.2 establish four approaches, and this framework is canonical for both physical and biological condition accounts ([TG-4.9](#) cross-refers here).

Approach	Description
Historical / pre-impact baseline	Earliest available consistent dataset for the accounting unit (national monitoring series, paleoecological records, legacy survey data).
Pristine or least-disturbed reference site	Minimally impacted contemporary site of equivalent ecosystem type, biogeographic region, and depth range.
Modelled natural state	Model-derived estimate calibrated on undisturbed sites; used where empirical references are unavailable.
Regulatory or management target	Policy-defined value (e.g., MPA recovery target, CBD Kunming-Montreal GBF Target 3); least preferred, flag explicitly.

¶7 **Fixed reference condition for time-series accounts.** For time-series accounting, the reference condition value for each indicator must be fixed at the start of the series and held constant across all subsequent periods. Revisions are permitted only at a formally documented major methodological review and require complete re-compilation of the historical series from the new baseline. Document the reference-condition vintage (year established) in account metadata. New accounting units introduced mid-series establish their own baseline at first measurement, and are flagged as a new series start.

¶8 **Ecosystem-specific physical priorities** vary by habitat type:

Habitat type	Key physical condition variables	Notes
Coral reef	SST anomaly, pH/ Aragonite, turbidity	Thermal bleaching and acidification are primary stressors; see §3.2 for coral-specific SST rescaling
Seagrass and saltmarsh	Water clarity (Kd490), dissolved inorganic nutrients, salinity	Light availability governs productivity

Habitat type	Key physical condition variables	Notes
Mangrove	Salinity, turbidity, tidal inundation frequency	Salinity tolerance range defines condition envelope
Open ocean / pelagic	SST, dissolved oxygen, mixed layer depth	Oxygen minimum zone expansion is a key condition trend; see §3.2 for MLD guidance

¶9 For detailed habitat-specific guidance, see [TG-6.1 Coral Reef Ecosystem Accounting](#), [TG-6.2 Mangrove and Coastal Wetland Accounting](#), [TG-6.3 Seagrass Ecosystem Accounting](#), and [TG-6.5 Pelagic and Open Ocean Accounting](#).

3.2 Indicator Selection

¶1 Indicators are selected according to four criteria set out in SEEA EA paras 5.22–5.27. Table 3.2.1 below summarises these criteria.

Criterion	Description
Measurability	The variable can be quantified with available technology at the required spatial and temporal resolution.
Ecological relevance	It reflects a key aspect of ecosystem functioning or integrity for the habitat type in question.
Sensitivity to change	It responds detectably to the pressures of concern within the accounting period.
Data availability	Consistent national or regional time series exist or can be established within the capacity of the compiling agency.

¶2 Recommended physical condition indicators by ECT class

¶3 ECT Class A1 – Physical state characteristics

- ¶4 **Sea Surface Temperature (SST)**: primary indicator of thermal stress and climate forcing. Unit: °C. Reference condition: long-term climatological mean (e.g., the 1985–2012 NOAA Coral Reef Watch CoralTemp climatology²). Where the full 1985–2012 period is unavailable nationally, use the longest consistent national record as the reference baseline, document the period explicitly in metadata, and note the departure from the global standard baseline. Rescaling: temperature anomaly relative to baseline. The condition indicator decreases as anomaly increases above the reference variability range. *For coral reef accounting units*: threshold-based rescaling using the Maximum Monthly Mean (MMM) climatology is the preferred approach. When sea surface temperature exceeds the MMM, Degree Heating Weeks (DHW) begin to accumulate, and $DHW \geq 8^{\circ}\text{C-weeks}$ corresponds to significant bleaching risk. The MMM/DHW method is the global operational standard for bleaching heat-stress monitoring. NOAA Coral Reef Watch provides ready-to-use global 5-km DHW and MMM products.² The same indices can equally be derived from Copernicus Marine Service (CMEMS) or ESA Climate Change Initiative (CCI) SST inputs where an alternative provider is preferred.
- ¶5 **Salinity**: indicator for estuarine and coastal boundary zones. Unit: practical salinity units (PSU). Reference condition: long-term climatological mean from WOA³ or ARGO programme⁴ for the accounting unit.
- ¶6 **Water clarity / light attenuation (Kd490)**: relevant for seagrass and coral light requirements. Unit: m^{-1} . Reference condition: site-specific long-term mean from satellite ocean colour products. Condition indicator decreases as Kd490 increases beyond the reference level (higher attenuation = reduced light penetration = poorer condition).
- ¶7 **Mixed layer depth (MLD)**: indicator of ocean stratification and vertical mixing, relevant for pelagic and open-ocean accounting units. Unit: metres. Reference condition: long-term climatological mean MLD from ARGO programme or CMEMS reanalysis. Shoaling of MLD beyond the climatological range indicates increased stratification, which constrains nutrient upwelling and

affects productivity. Condition indicator decreases as MLD shoals beyond the climatological reference range. Source: ARGO programme density profiles; CMEMS physical reanalysis products. See [TG-6.5 Pelagic and Open Ocean Accounting](#) for guidance on MLD in pelagic condition accounts.

¶8 ECT Class A2 – Chemical state characteristics

- ¶9 **Ocean pH / aragonite saturation (Ω)**: indicator of ocean acidification state. Unit: pH units (dimensionless Ω). Reference condition: pre-industrial pH (~8.18) or a regional multi-decadal baseline from SOCAT/GLODAP. Condition indicator decreases as pH declines or Ω falls below the aragonite saturation threshold ($\Omega = 1$), below which shell-forming organisms cannot maintain calcified structures.
- ¶10 **Dissolved oxygen (DO)**: indicator of habitat viability and eutrophication stress. Unit: mg/L or % saturation. Hypoxia threshold: <2 mg/L (below which most marine fauna cannot persist). Reference condition: site-specific or regional historical baseline.
- ¶11 **Dissolved inorganic nutrients (NO_3 , PO_4)**: eutrophication indicators for coastal zones. Unit: $\mu\text{mol/L}$. Reference condition: oligotrophic background level for the relevant ocean region. Condition indicator decreases as nutrient concentrations exceed reference levels.

¶12 Tiered indicator selection approach

¶13 Indicator selection follows a three-tier framework based on data availability. The tiering draws on the graduated capacity framework described in [TG-0.7 Quality Assurance Principles](#). Table 3.2.2 below summarises the three tiers.

Tier	Description
Tier 1	Variables with nationally monitored, consistent time series of at least 10 years. These are the preferred source for condition trend assessment. In-situ networks and national survey programmes are the primary data source.
Tier 2	Variables derived from model output or regional satellite products where in-situ series are absent or incomplete. The CMEMS Physical Analysis and Forecast System ⁵ and satellite-derived ocean colour composites are typical Tier 2 sources. Trend assessment requires the full 1993–present satellite altimetry era where possible.
Tier 3	Data-poor contexts where global reanalysis climatologies (WOA decadal climatologies and 1991–2020 climate normals, ERA5-ocean) provide the only available series. Tier 3 variables carry the highest uncertainty and should be flagged as such in condition account metadata.

¶14 Rescaling and aggregation pathway

¶15 The transition from raw measurement to reported condition indicator follows three steps, consistent with SEEA EA paras 5.44–5.58. Figure 4.8.1 traces the pathway from a raw ECT Class A1 or A2 variable, through quality control and benchmarking against the reference condition, to a rescaled and aggregated SEEA EA Table 5.2 condition account row. Table 3.2.3 below summarises these steps.

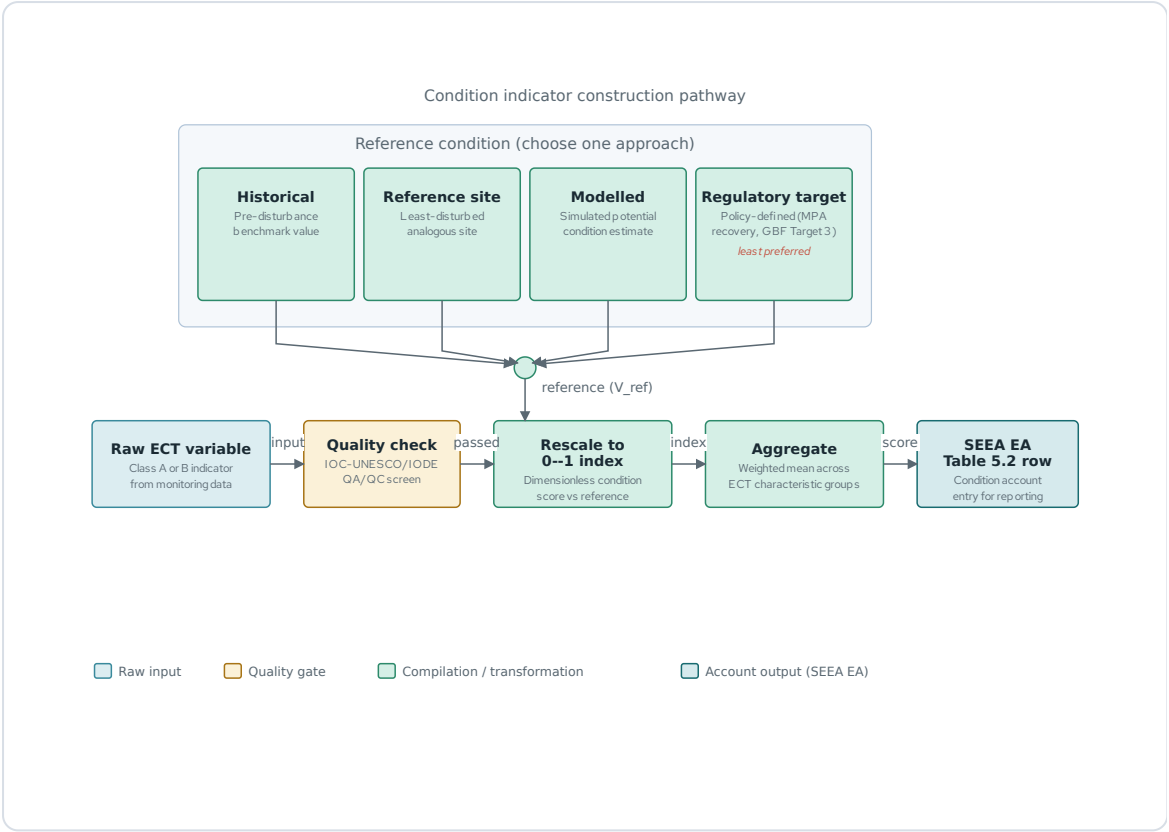


Figure 4.8.1 Pathway from an ECT Class A or B variable through quality check, reference benchmarking, rescaling, and aggregation to a SEEA EA Table 5.2 row. Four reference-condition approaches; regulatory or management target is least preferred.

Source: TG-4.8, §3.1--3.5 (conceptual framework, indicator selection, measurement & integration); ECT Class A/B structure per SEEA EA 2024 Table 5.1; reference-condition approaches per SEEA EA 2024 §§5.65--5.75 and Appendix A5.2.

Step	Description
Raw variable normalisation	Standardise units, apply quality flags, and aggregate to the spatial and temporal resolution of the accounting unit.
Rescaling to 0–1 condition indicator	Apply the rescaling function (see §3.5 for the explicit formula) to map the variable onto the 0–1 condition scale relative to the reference condition.
ECT-class and composite indices	Aggregate individual condition indicators within each ECT class (A1, A2) to produce class-level and whole-ecosystem condition indices, following the weighting approach documented by the compiling agency. Cross-reference TG-2.1 Aggregate Biophysical Indicators of Environmental State for indicator aggregation methods.

3.3 Measurement Protocols

¶1 In-situ measurement

¶2 CTD (conductivity-temperature-depth) casts provide vertical profiles of temperature, salinity, and (where equipped) dissolved oxygen and fluorescence. Moored buoys record continuous surface and sub-surface time series. ARGO profiling floats provide open-ocean profiles to 2,000 m depth with near-real-time transmission. Repeat hydrography programmes (WOCE/GO-SHIP sections) supply basin-scale reference data for calibration.

¶3 For coastal and estuarine zones, national tide gauge networks, fixed moored sensors, and periodic survey cruises provide the primary in-situ data. Water sampling for nutrient and pH analysis should follow IOC-UNESCO/IODE standard operating procedures, including certified reference materials for pH (NOAA-distributed CRMs) and oxygen (Winkler titration).

¶4 Remote sensing

¶5 Satellite-derived SST (MODIS Aqua, AVHRR, Sentinel-3 SLSTR) provides daily global coverage with approximately 1 km spatial resolution. Ocean colour products (MODIS Aqua, SeaWiFS, Sentinel-3 OLCI) deliver Kd490 and turbidity estimates at 300 m – 4 km resolution. Gap-filling via optimal interpolation (OI) is standard for SST products (NOAA OISST, CMEMS, GHRSSST Level 4). See [TG-4.1 Remote Sensing and Geospatial Data](#) for sensor selection and pre-processing protocols.

¶6 Tiered minimum time requirements

¶7 Table 3.3.1 below summarises the minimum time-coverage requirements for each tier.

Tier	Minimum time requirement
Tier 1	A minimum of 10 years of consistent observations is required for trend-reliable condition assessment; longer series should be used where available to capture multi-decadal variability.
Tier 2	Satellite-era products should span the full 1993–present period where possible; where national capacity limits coverage, use the longest available continuous record and document the gap in metadata.
Tier 3	WOA decadal climatologies, or the 1991–2020 climate normal, are the minimum standard. The WOA 2023 edition (Reagan et al. 2024) ³ is the current default; report the specific WOA edition and climatological period used in all metadata.

¶8 Abiotic SOP references

¶9 The standards listed in Table 3.3.2 are the canonical SOPs for the abiotic variables enumerated in Section 3.2. Compiling agencies should record the cited standard (and its version/year) in metadata for each variable per **TG-0.7 Quality Assurance Principles**. Documented departures from the SOP (sampling depth, replication, gear substitution) should be recorded alongside the measurement. Satellite-derived alternatives are listed in the remote-sensing subsection above and in Table 3.4.

Variable	Measurement / sample type	Standard protocol	Source
Temperature, salinity (profile)	CTD cast, WOCE/GO-SHIP-compatible QA	GO-SHIP repeat-hydrography protocol; IOC-UNESCO/IODE Manuals & Guides 54 ⁶ , ⁷	go-ship.org
Dissolved oxygen (discrete)	Winkler titration on bottle samples	IOC-UNESCO/IODE Manual; ISO 5813 / ISO 5814 ⁸	IOC-UNESCO; ISO
Dissolved oxygen (in-situ profile)	Calibrated optode on CTD or BGC-Argo	BGC-Argo Quality Control Manual ⁹	Argo Data Management Team
pH / pCO ₂ / aragonite saturation	Discrete bottle samples; CRM-referenced spectrophotometric pH	Dickson et al. (2007) <i>Guide to Best Practices for Ocean CO₂ Measurements</i> ; SOCAT and GLODAP submission protocols ¹⁰	PICES Special Publication 3
Nutrients (NO ₃ , PO ₄ , SiO ₄)	Auto-analyser on filtered water samples	GO-SHIP nutrient protocol; ISO 13395 (nitrate); ISO 6878 (phosphate) ⁷ , ¹¹	IOC/GO-SHIP; ISO
Turbidity / Kd490 (in-situ)	Secchi depth; PAR profiler	IOC-UNESCO ocean optics protocols (Mueller & Fargion 2003) ¹²	NASA Ocean Optics Protocol Revisions

Variable	Measurement / sample type	Standard protocol	Source
Sediment grain size, organic carbon	Sediment grab/core; sieving and loss-on-ignition or elemental analyser	ISO 16665 (marine benthos sampling); ISO 11464 (sample pretreatment) ¹³	ISO

¶10 Quality control and data-poor contexts

¶11 Apply IOC-UNESCO/IODE QA procedures (anomaly flagging, measurement precision, gap-filling documentation) within the **TG-0.7** framework. All stations georeferenced to WGS84. Annual composites are the minimum for accounts. Where national in-situ programmes are limited, global reanalysis (CMEMS, ERA5-ocean, WOA) is a viable Tier 3 alternative. Document source, version, and known biases, especially in shallow coastal and enclosed seas. Supplement with **TG-4.4 Citizen Science** data where coverage is sparse.

3.4 Data Requirements and Sources

¶1 The following matrix specifies the minimum data requirements for each recommended physical condition indicator:

Variable	Unit	Primary Source	Update Frequency (accounts: annual composite recommended)	Data-Poor Alternative
Sea Surface Temperature	°C	NOAA OISST / CMEMS SST	Daily source; monthly composites; annual mean for accounts	HadISST reanalysis (monthly, 1°×1°)
Salinity	PSU	ARGO programme / national CTD surveys	Monthly profiles; annual climatology for accounts	World Ocean Atlas (decadal climatology; 1991–2020 normal)
Dissolved Oxygen	mg/L	ARGO BGC floats / moored sensors	Near-real-time profiles; annual composite for accounts	World Ocean Database reanalysis fields
pH / Ωaragonite	pH / dimensionless	SOCAT, GLODAP, ARGO BGC	SOCAT/GLODAP: annual update; ARGO BGC: near-real-time; annual composite for accounts	CMEMS biogeochemical analysis and forecast
Water clarity (Kd490)	m ⁻¹	MODIS Aqua / Sentinel-3 OLCI	Monthly composites; annual mean for accounts	CMEMS ocean colour multi-observation product
Dissolved inorganic nutrients	µmol/L	National marine surveys / ICES Data Centre	Annual survey; near-real-time for some ICES regions; annual composite for accounts	World Ocean Atlas (all-years climatology; WOA publishes no decadal nutrient fields)
Mixed layer depth	m	ARGO programme density profiles / CMEMS physical reanalysis	Monthly profiles; annual mean for accounts	CMEMS global ocean reanalysis (GLORYS12)

¶12 **Key institutional data sources:** Copernicus Marine Service (CMEMS), NOAA CoastWatch, NOAA Coral Reef Watch, IMOS (Australia), ICES Data Centre, IOC-UNESCO IODE, national oceanographic institutes, national meteorological services, Argo Data Assembly Centres (GDAC).

¶13 **Known data limitations:**

- ¶4 Sparse in-situ coverage in developing-country EEZs creates reliance on Tier 2–3 products with higher uncertainty.
- ¶5 Satellite retrievals are degraded by cloud cover, sun glint, river plumes, and coastal adjacency effects within approximately 1 km of the shoreline.
- ¶6 Reanalysis products may not resolve sub-mesoscale processes in enclosed seas, shallow bays, or areas of strong tidal forcing.
- ¶7 BGC-ARGO pH and oxygen profiles are sparse in coastal and shelf regions, whilst WOD/GLODAP cover is more complete in the open ocean.
- ¶8 MLD estimates from density profiles are sensitive to the threshold criterion applied (density or temperature criterion), and the criterion used must be documented for reproducibility.

¶9 Compiling agencies should document data source, product version, spatial resolution, and temporal coverage for every variable in the condition account metadata. See [TG-4.6 Data Harmonisation and Interoperability](#) for guidance on integrating data from multiple sources.

3.5 Reporting and Integration

¶1 Reporting format

¶2 Each physical condition variable is delivered with the following fields: ECT class, variable name, unit of measurement, reference condition value, current condition value, and rescaled condition indicator (0–1 scale). Arranging those fields as rows of the SEEA EA Table 5.2 condition account is done in **TG-3.1 Asset Accounts** Section 3.5.2; combining variables into an ECT-class or overall condition index is **TG-2.1 Aggregate Biophysical Indicators of Environmental State**. This Circular is responsible for the variable and its rescaling to a 0–1 score against a documented reference, not for the aggregate or the account.

¶3 Rescaling formula

¶4 For variables where higher values indicate better condition (e.g., dissolved oxygen, aragonite saturation):

$$CI = (V - V_{min}) / (V_{ref} - V_{min})$$

¶5 For variables where lower values indicate better condition (e.g., temperature anomaly, nutrient loading, turbidity):

$$CI = 1 - [(V - V_{min}) / (V_{max} - V_{min})]$$

¶6 Where:

- ¶7 CI = condition indicator (0–1 scale; 1 = at or above reference condition; 0 = fully degraded or absent)
- ¶8 V = observed variable value for the accounting period
- ¶9 V_{ref} = reference condition value (the value of the variable under the chosen reference condition)
- ¶10 V_{min} = minimum observed value or ecologically meaningful lower bound (e.g., 0 mg/L for dissolved oxygen; Ω_{aragonite} = 0; pH = 7.75). Examples by variable: dissolved oxygen V_{min} = 0 mg/L; Ω_{aragonite} V_{min} = 0; pH V_{min} = 7.75; temperature anomaly V_{min} = 0. Compiling agencies must document the V_{min} and V_{max} values applied for each variable, and deliver them alongside the variable.
- ¶11 V_{max} = maximum observed value or ecologically meaningful upper bound (used in negative-condition formula only)

¶12 For binary threshold indicators (e.g., DO hypoxia): CI = 1 if $V \geq \text{threshold}$ (2 mg/L), and CI = 0 if $V < \text{threshold}$ (step rescaling). Figure 4.8.2 works a numerical example of these formulas: continuous-variable rescaling (an SST anomaly on a coral reef unit) and threshold (step) rescaling (dissolved oxygen about the hypoxia threshold). Its third panel shows, for orientation only, where the delivered scores go – the ECT-class aggregate and the Table 5.2 rows are compiled under TG-2.1 and TG-3.1 respectively, not here.

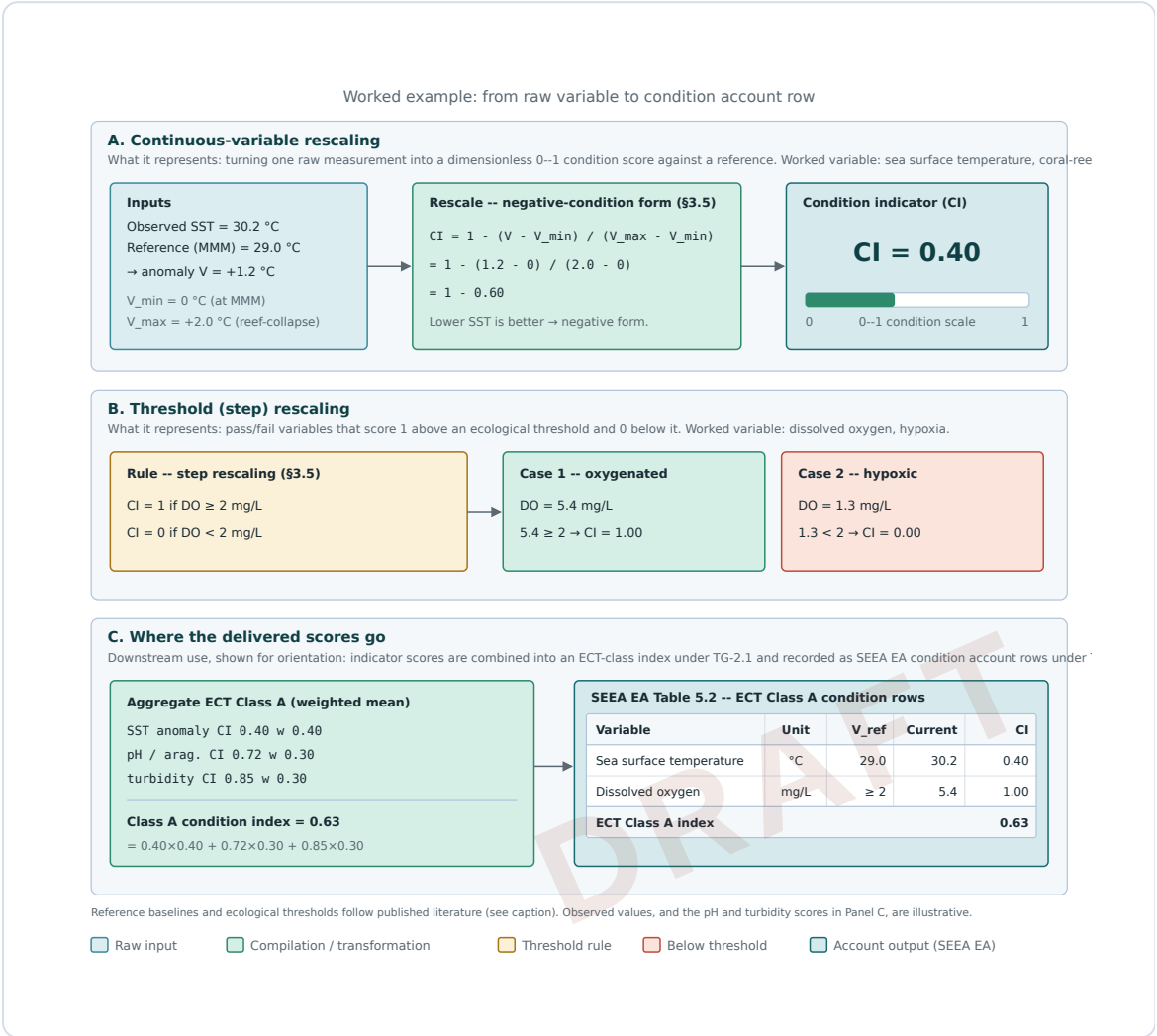


Figure 4.8.2 Panels A and B show the rescaling this Circular performs: continuous rescaling and threshold rescaling. Panel C shows where the resulting scores go -- ECT Class A aggregation and SEEA EA Table 5.2 rows, both compiled elsewhere. Observed values and weights are illustrative.

Source: TG-4.8 §3.5 (rescaling, bounds, binary threshold); TG-2.1 (aggregation); TG-3.1 §3.5.2 (condition account); SEEA EA 2024 §§5.44--5.58 and Table 5.2. Baselines: Liu et al. 2014 (MMM/DHW); IPCC 2018 / Frieler et al. 2013 (+2°C); Diaz & Rosenberg 2008 / Vaquer-Sunyer & Duarte 2008 (2 mg/L hypoxia).

¶13 Where current condition exceeds the reference baseline ($CI > 1$ in the positive-condition formula), CI is delivered as 1.0 and the raw calculated value is recorded in the accompanying metadata. A CI above 1 can arise where recent conservation gains have improved condition above the historical reference.

¶14 **Integration with biological condition**

¶15 Physical variables establish the abiotic habitat envelope for **TG-4.9** indicators. Joint reporting of SST, DO, turbidity, and pH enables attribution analysis (e.g., distinguishing thermal stress from direct anthropogenic impact).

¶16 **Uncertainty reporting**

¶17 Each indicator requires measurement-uncertainty, representativeness, and model-uncertainty components, plus the data tier (1–3) and gap-filling method. Metadata documentation follows **TG-0.7**.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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